Nature Conservation 44: 51–68 (2021)
doi: 10.3897/natureconservation.44.63270
https://natureconservation.pensoft.net

REVIEW ARTICLE

A peer-reviewed open-access journal
Nature Conservation
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# Recreation effects on wildlife: a review of potential quantitative thresholds

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Academic editor: G.V. Gopi | Received 19 January 2021 | Accepted 20 April 2021 | Published 28 May 2021

*http://zoobank.org/E7A7CE40-1412-4F59-AF72-5C580AB8274B*

**Citation:** Dertien JS, Larson CL, Reed SE (2021) Recreation effects on wildlife: a review of potential quantitative thresholds. Nature Conservation 44: 51–68. https://doi.org/10.3897/natureconservation.44.63270

## Abstract

Outdoor recreation is increasingly recognised for its deleterious effects on wildlife individuals and populations. However, planners and natural resource managers lack robust scientific recommendations for the design of recreation infrastructure and management of recreation activities. We reviewed 38 years of research on the effect of non-consumptive recreation on wildlife to attempt to identify effect thresholds or the point at which recreation begins to exhibit behavioural or physiological change to wildlife. We found that 53 of 330 articles identified a quantitative threshold. The majority of threshold articles focused on bird or mammal species and measured the distance to people or to a trail. Threshold distances varied substantially within and amongst taxonomic groups. Threshold distances for wading and passerine birds were generally less than 100 m, whereas they were greater than 400 m for hawks and eagles. Mammal threshold distances varied widely from 50 m for small rodents to 1,000 m for large ungulates. We did not find a significant difference between threshold distances of different recreation activity groups, likely based in part on low sample size. There were large gaps in scientific literature regarding several recreation variables and taxonomic groups including amphibians, invertebrates and reptiles. Our findings exhibit the need for studies to measure continuous variables of recreation extent and magnitude, not only to detect effects of recreation on wildlife, but also to identify effect thresholds when and where recreation begins or ceases to affect wildlife. Such considerations in studies of recreation ecology could provide robust scientific recommendations for planners and natural resource managers for the design of recreation infrastructure and management of recreation activities.

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**Keywords**
Distance to people, human disturbance, park management, protected areas, recreation impacts, wildlife conservation

## Introduction

Human disturbance is widely recognised for its deleterious effects on the physiology, behaviour and demographics of individuals and populations of wild animals (Steven and Castley 2013; Coetzee and Chown 2016). Sources of disturbance are extremely diverse and include mortality from hunting and roadkill (Scillitani et al. 2010) to non-consumptive sources, such as hiking, boating and wildlife watching (Cowling et al. 2015; Tarjuelo et al. 2015). Whereas the population- or community-level effects of human disturbance via take are more apparent, effects of non-consumptive human disturbance on wildlife physiology and behaviour are less easily identified or separated from other confounding environmental factors. A growing body of research has focused on the effects of non-consumptive human disturbance with a specific focus on outdoor recreation (Larson et al. 2016).

Outdoor recreation is growing rapidly around the world and has been identified as one of the greatest threats to protected areas (Balmford et al. 2015; Schulze et al. 2018). In the United States, visitation to developed recreation sites is projected to increase by 23% by 2030 (White et al. 2014). Human disturbance on wildlife from non-consumptive recreation can result in altered spatiotemporal habitat use (Kangas et al. 2010; Rösner et al. 2014), decreased survival and reproduction (Iverson et al. 2006; Baudains and Lloyd 2007) and, ultimately, decreased population abundance (Miller et al. 1998; Bejder et al. 2006) or extirpation from otherwise suitable habitat (Steven and Castley 2013). To reduce or eliminate negative effects of recreation on wildlife, land managers require explicit recommendations for how to design trails, manage visitors and otherwise balance the multi-use objectives of many protected areas.

Identifying the effect threshold or the point at which wildlife begins to be disturbed by such recreation activities is key to providing informed recommendations to land managers and planners attempting to make decisions regarding infrastructure construction and visitor management (Braunisch et al. 2011; Rösner et al. 2014; Monz et al. 2016). Data on effect thresholds give protected area planners and managers a better understanding of, for example, the overall effect area for each trail (Lenth et al. 2008), buffer zones around birds of prey nests (Swarthout and Steidl 2001; Keeley and Bechard 2011) and evidence to defend limits on visitation numbers or seasonal closures (Schummer and Eddleman 2003; Malo et al. 2011). Researchers who study the effects of recreational activities on wildlife often attempt to estimate quantitative effects thresholds as effect distances from people or infrastructure (Pittfield and Burger 2017; Bötsch et al. 2018), density of trails and other infrastructure (Braunisch et al. 2011; Harris et al. 2014) or visitation rates (Kerbiriou et al. 2009; Malo et al. 2011).

Elucidating an effect threshold can be difficult because a threshold may not exist, the study sample was not large enough or inferring an effect threshold was not of interest during the study design. Therefore, often the mean distance, mean disturbance intensity or an index of disturbance is reported rather than an effect threshold (Bennett et al. 2013; Costello et al. 2013). The mean effect level is important and valuable information for conservation, but likely does not capture the point at which all or, at least, a large portion of wildlife individuals are affected. Estimating the complete extent of potential recreation impacts provides a more complete robust assessment for conservation planning.

Our objective was to identify quantitative thresholds of non-consumptive recreation in order to provide clearer data to nature professionals about the potential extents and limits of recreation impacts on wildlife. We conducted a systematic review of the published scientific literature of non-consumptive human recreation effects on wildlife in terrestrial environments. We analysed articles to determine if the authors detected a quantitative threshold where recreation began to impact wildlife at the individual, population or community level or cause habitat degradation. We summarise the findings descriptively, reviewing the species and ecosystems that have been studied and identifying gaps in the available literature. We identify quantitative thresholds across a wide array of recreation activity types, wildlife species and response measurements which only allow summation of our findings across broad categories. In addition, we investigated whether the threshold effect depends on body size, predicting a positive relationship between body size and quantitative thresholds (i.e. larger birds and mammals would respond to disturbance at further distances) (Blumstein et al. 2005; Piratelli et al. 2015; Battisti et al. 2019). Finally, we discuss the limitations of these findings and how future research should consider study designs that explore the quantitative thresholds of systems as a means of providing the best recommendations for natural resource professionals.

## Methods

We used a database of primary literature compiled for a systematic review of the effects of recreation on wildlife (Larson et al. 2016), supplemented with additional articles published through December 2018 that matched the criteria of Larson et al. (2016) for a total of 38 years of publications. Their criteria were limited to journals (n = 166) in the Web of Science database (Thompson Reuters, New York, NY, USA) in the categories: biodiversity conservation, ecology, zoology and behavioural sciences. The criteria included articles that focused on non-consumptive human recreation activities (i.e. did not include hunting or fishing), studied one or more animal species, assessed recreation effects using statistical tests and were published in English. For the purpose of our review of quantitative thresholds, we included only studies of terrestrial species or interactions with aquatic animals while they were on land. This resulted in 330 articles remaining in our database.

We sought to determine which papers identified a minimum effect threshold, which we defined as the point at which ≥ 90% of sampled wildlife individuals already showed a behavioural or physiological response (e.g. flushing, increased heart rate) to a recreation disturbance or the point at which recreation disturbance begins to reduce the presence, abundance or survival probability of a population or degrade the habitat. For example, Thomas et al. (2003) found that 96% of sanderlings (*Calidris alba* Pallas, 1764) were disturbed at a distance of ≤ 30 m and Malo et al. (2011) found that detections of guanaco (*Lama guanicoe* Müller, 1776) began to reduce at > 250 visitors/day. We chose this definition because of the preponderance of studies that identified the 90$^{th}$ or 95$^{th}$ percentile of threshold distance (Swarthout and Steidl 2001; Muposhi et al. 2016). A threshold of habitat degradation was highly study-specific and, therefore, was generally the point at which a specific paper's metric of habitat alteration began to exhibit a negative change correlated with recreation (Bennett et al. 2013). We did not include papers that reported only the mean level of disturbance (e.g. mean flush distance, mean recreation group size), as this value does not represent the full distribution of disrupted animals. We did include papers that presented graphical representations that allowed for estimation of a threshold effect, even if that threshold was not explicitly stated in the article text.

We recorded the details of each quantitative threshold, including the measure of wildlife or indirect response (behavioural, occurrence, physiological, relative abundance, reproduction and habitat degradation), the measure of recreation disturbance (e.g. number of visitors, distance to people) and the value at which the disturbance threshold was observed (e.g. > 14 visitors/day, < 100 m from people). Some articles recorded multiple threshold effects per species that varied by season or recreation type; therefore, several articles had multiple database inputs. To avoid pseudo-replication, we took the largest threshold response if there were multiple values for one species across seasons or for the same recreation activity. We did record all values across different recreation types for the same species since recreation types can be viewed as different treatments. We classified each article into nine different ecosystem classifications alpine/tundra, coast/shoreline, desert, forest, grassland, polar, savannah, scrub/shrub and wetland. Studies were classified into all the ecosystems that the authors identify in the paper. In addition, we extracted details on study type (e.g. observational or experimental), species of interest and publication information.

We further binned each paper based on recreation activities into either hiking-only, multi-use non-motorised or motorised categories. This was done in order to compare threshold effects across general recreation types. The multi-use non-motorised included both papers that had hiking as one of multiple activities and the motorised category included papers that were motorised-only and which had multiple motorised and non-motorised recreation activities. We used a single-factor analysis of variance to test if there was a significant difference in the threshold effects amongst these recreation categories.

Finally, we researched body masses for all bird and mammal species (Dunning 2007; Williamson et al. 2013) and used linear regression to analyse the relationship between mass and effect distance for birds and mammals separately, with body mass as an explanatory variable. We excluded two studies on flightless birds given the mass

disparity to flighted birds and two studies on mammal populations that were habituated to close human presence. We log-transformed bird ($n$ = 50) and mammal ($n$ = 21) body mass and effect distance to conform to assumptions of normality. Significance of all tests was set at 0.05 and analyses were performed in programme R (R Core Development Team 2020).

## Results

We reviewed 330 journal articles, of which 53 articles identified one or more quantitative threshold effects. The vast majority of the 53 articles focused on bird or mammal species, with little representation of invertebrates, amphibians or reptiles. Studies of birds focused primarily on species in the orders Charadriiformes (e.g. wading birds and gulls), Accipitriformes (e.g. hawks, eagles and vultures) and Passeriformes (i.e. perching birds) (Fig. 1A). Studies of Strigiformes (i.e. owls) and Galliformes (i.e. upland birds) were notably under-represented. Mammal studies primarily focused on species in the orders Artiodactyla (i.e. even-toed ungulates) and Carnivora (i.e. bears and cats) (Fig. 1B).

Studies that identified threshold effects were conducted predominately in forest or coastal/shoreline ecosystems with limited representation in the other ecosystems (Fig. 2A). Hiking was by far the most studied recreational activity, followed by wildlife viewing on land, beach use and dog-walking (Fig. 2B). Most studies examined only non-motorised activities (71.7%), while fewer studies examined only motorised activities (15.1%) or both (13.2%). Nearly half (39.6%) of the articles examined two or more recreation activities, two-thirds of which included hiking as one of the activities.

Quantitative thresholds were identified for a variety of recreation disturbance variables, but can be generally grouped into distance effects, visitation rates and infrastructure density effects (Fig. 2C). Distance effects included distance to people, trails and vehicles. Studies that focused on the distance effects to people included observational studies in coastal ecosystems where trails are less well defined and quasi-experimental studies, in which researchers approached individual animals to measure alert and flight initiation distances. Quantitative thresholds for distance to trail were identified in studies of birds, mammals and invertebrates. Several studies were precluded from the possibility of finding a threshold effect because the researchers only focused on categorical differences between trail types.

Articles examining thresholds of visitation rates or the number of people or vehicles per unit time, were comparatively less well represented (Fig. 2C). Those measuring threshold numbers of people focused on human visitation effects on primate group behaviour, decreasing detections correlated with increasing magnitude of visitation and behavioural disturbance to animals from tourist group visits to wildlife concentrations. Visitor numbers, as low as one person or off-road vehicle per day, were shown to negatively affect the habitat use of studied species in some cases. Very few articles focused on or found recreation infrastructure density effect thresholds (Fig. 2C).

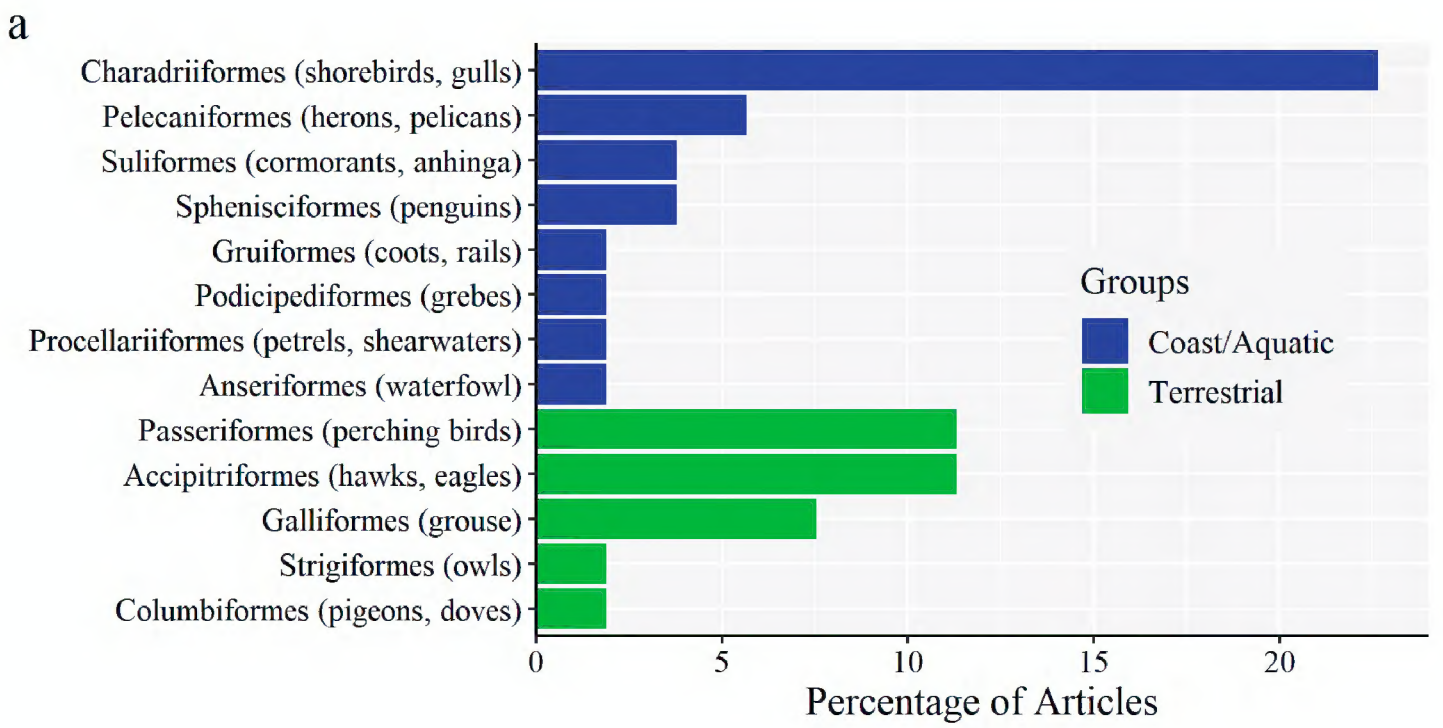


**Figure 1.** Recreation effect threshold articles by bird and mammal orders **(a)** bird and **(b)** mammal orders studied in papers that identified an effect threshold. Several articles contained more than one order, thus, the total number of articles sums to more than all the threshold effects papers.

The vast majority of threshold studies focused on the behavioural response of wildlife to a human disturbance, followed by measurements of occurrence and relative abundance (Table 1). Of the behavioural response measurements, over half were measured as a flight initiation distance (i.e. the distance at which wildlife began to move due to a human disturbance). Other behaviour measurements included the number of wildlife individuals feeding or standing, vigilance behaviour and changes in activity budget; however, each of these was measured in less than 4% of papers. Occurrence measurements were a derivation of presence or detection and abundance measurements included counts of individuals or faecal pellet densities. Physiological, reproductive or habitat degradation response thresholds were represented in less than 2% of papers (Table 1).

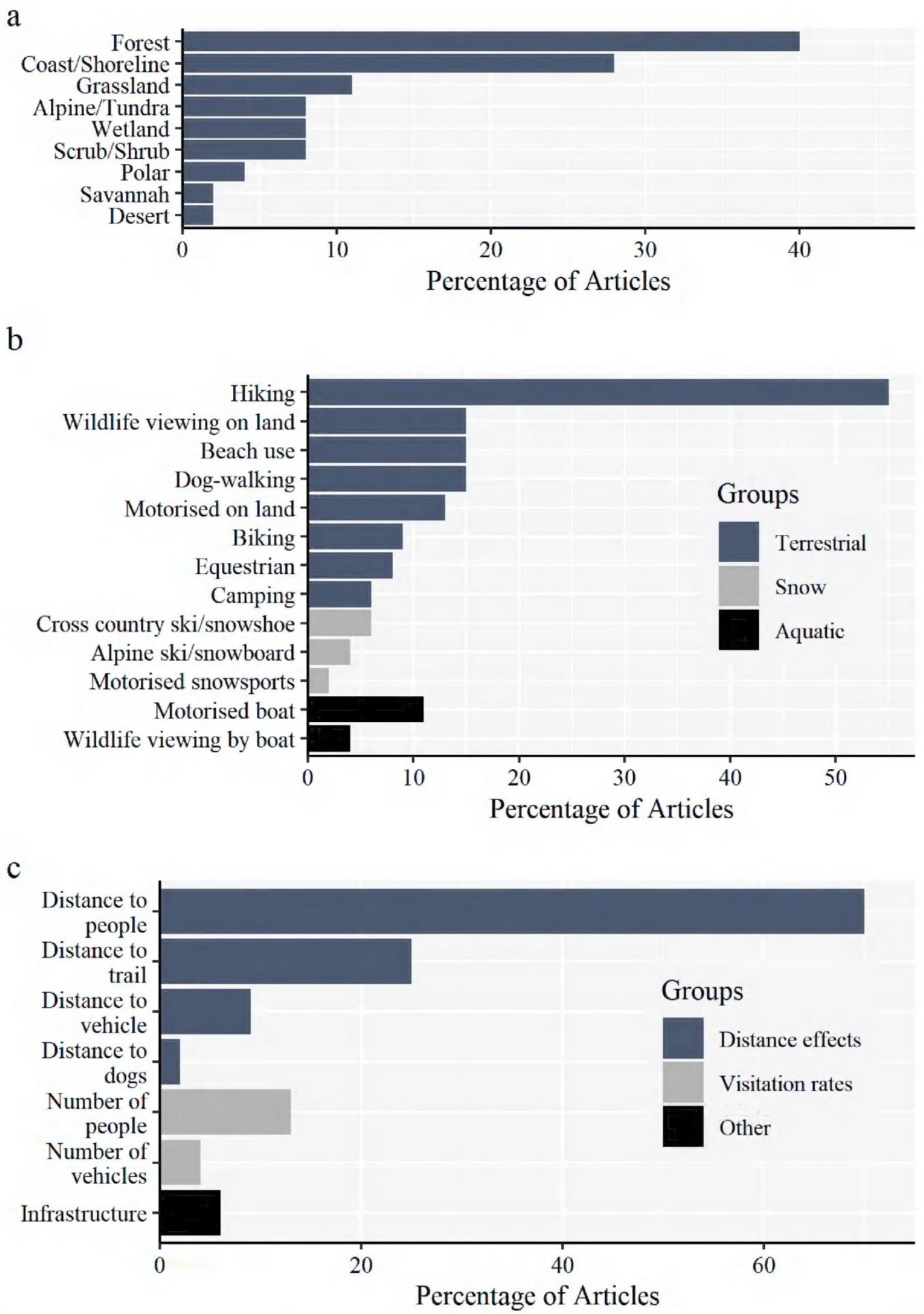


**Figure 2.** Descriptive statistics of recreation threshold articles. Summary of **a** ecosystem types **b** recreation activities and **c** disturbance variables of articles that identified an effect threshold. Several papers studied more than one ecosystem, recreation activity or disturbance variable, therefore, percentages in one plot sum to greater than 100%. Aquatic recreation only included those water-based activities that effected wildlife on land. Disturbance variable distance to trail included all forms of recreation (e.g. motorised, non-motorised and dogs allowed and not allowed) and infrastructure referred to density of human built strucutres.

**Table 1.** Wildlife response measurements across threshold articles. Measurement variables varied amongst the articles that identified an effect threshold. Habitat degradation was a measure of habitat response to recreation, an indirect effect to wildlife.

| General response | Measurement | % of Articles |
|---|---|---|
| Abundance | Density per site | 1.9 |
| | Number of birds observed | 1.9 |
| | Number of herds sighted daily | 1.9 |
| | Pellet density | 7.5 |
| | Relative abundance | 1.9 |
| | Track detections | 1.9 |
| Behavioral | Changes in activity budget of group | 1.9 |
| | Distance at which animal changed direction | 1.9 |
| | First reaction | 1.9 |
| | Flight initiation distance | 37.7 |
| | Max alert distance | 1.9 |
| | Number feeding or standing | 1.9 |
| | Number of moves | 1.9 |
| | Probability of active response | 1.9 |
| | Probability of disturbance | 1.9 |
| | Probability of flight | 1.9 |
| | Proportion of birds disturbed | 1.9 |
| | Time spent alert | 1.9 |
| | Time spent feeding/day | 1.9 |
| | Vigilance behavior | 3.8 |
| Habitat | Habitat degradation | 1.9 |
| Occurrence | Avoidance of human areas | 1.9 |
| | Community assemblage | 1.9 |
| | Habitat selection | 1.9 |
| | Presence | 11.3 |
| Reproduction | Monthly juvenile survival | 1.9 |
| Physiological | Heart rate | 1.9 |

Given the relatively low sample size of articles that identified thresholds, we were only able to make meaningful conclusions about distance thresholds for birds and mammals (Fig. 3). Distance thresholds from people and trails varied amongst orders and species. For example, wading birds and passerines were generally affected at distances less than 100 m, whereas larger-bodied species, such as hawks and eagles, had threshold effect distances greater than 400 m (Fig. 4). Smaller rodent species avoided areas within 50-100 m of trails or people, whereas some carnivores and ungulates had minimum effect distances anywhere from 40 to 1000 m from trails and people. The median effect threshold distance was 80.0 m for birds and 77.5 m for mammals and mean thresholds were 112.1 m and 151.1 m for birds and mammals, respectively (Fig. 4). We found evidence of a positive correlation between increasing body mass of flighted birds ($\hat{\beta} = 0.233$ SE = 0.052; $p < 0.001$) and effect distance threshold (Fig. 5). We did not find the same relationship between mammal body mass ($\hat{\beta} = 0.138$ SE = 0.102; $p = 0.192$) and effect distance threshold (Fig. 5).

Motorised recreation had the highest median threshold distance for birds (111.5 m), whereas multi-use non-motorised had the highest median value for mammals (100 m) (Fig. 6). Hiking-only recreation had the lowest median threshold distance for both

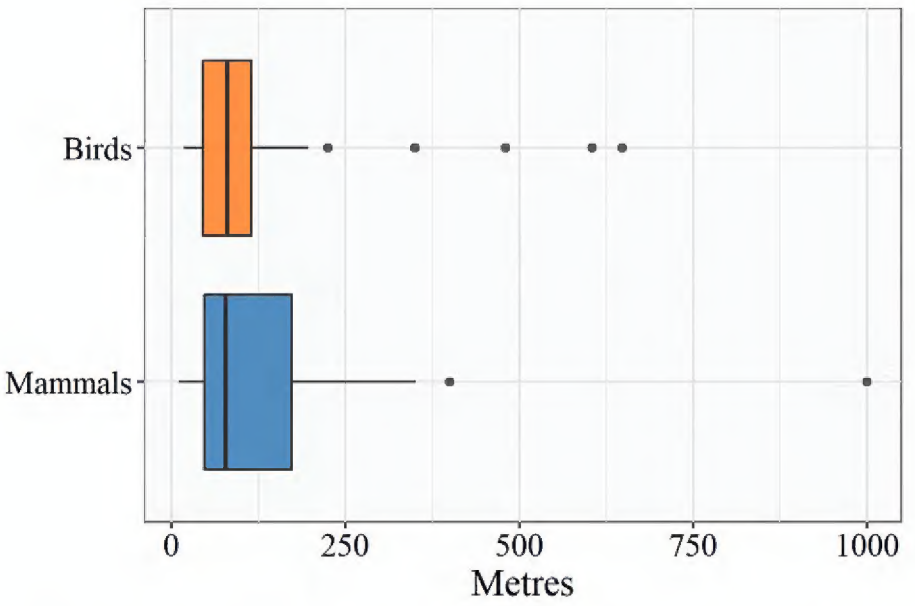


**Figure 3.** Distance of effect thresholds of birds and mammals. Effect distance thresholds across all mammal ($n$ = 24) and bird ($n$ = 53) species studied for the impacts of recreation on wildlife. Thresholds included observed distances of direct human disturbance to wildlife and disturbance from recreation infrastructure. Outliers for mammals are effect distances for larger ungulates. Outliers for birds are effect distances for raptors, including hawks and eagles. Boxplots indicate median and 25$^{th}$ and 75$^{th}$ percentiles. Whiskers extend to data 1.5 times the interquartile range.

birds (45 m) and mammals (40 m). However, there was substantial overlap of the distribution of values amongst all recreation types and single-factor ANOVA found no significant difference amongst recreation types for birds ($F$ = 0.066, $p$ < 0.936) or mammals ($F$ = 0.760, $p$ < 0.480).

## Discussion

There are numerous gaps in the scientific literature regarding quantitative thresholds of recreation effects on wildlife. While the publication rate on the recreation effects on wildlife has been increasing (Larson et al. 2016), there is still a need for science-based recommendations for management of recreation that present thresholds of disturbance. Further, certain taxonomic groups and ecosystems are substantially under-represented in this body of research. In this review, invertebrates were included in two articles and, while there are papers that have focused on reptile and amphibian behaviour (Moore and Seigel 2006; Bowen and Janzen 2008; Selman et al. 2013), we only found one paper each that presented evidence for a threshold to human disturbance on these taxa (Rodríguez-Prieto and Fernández-Juricic 2005; Pittfield and Burger 2017). Threshold studies were primarily conducted in forests or coastal ecosystems, with little representation of other ecosystems, especially deserts and savannahs.

We did however find numerous examples of minimum effect thresholds from certain taxa, especially shorebirds and ungulates. Studies of plover species (genera *Charadrius* and *Pluvialis*) provided some of the clearest examples of minimum effect thresholds and were primarily identified between 50-100 m (Fig. 4) (Lafferty

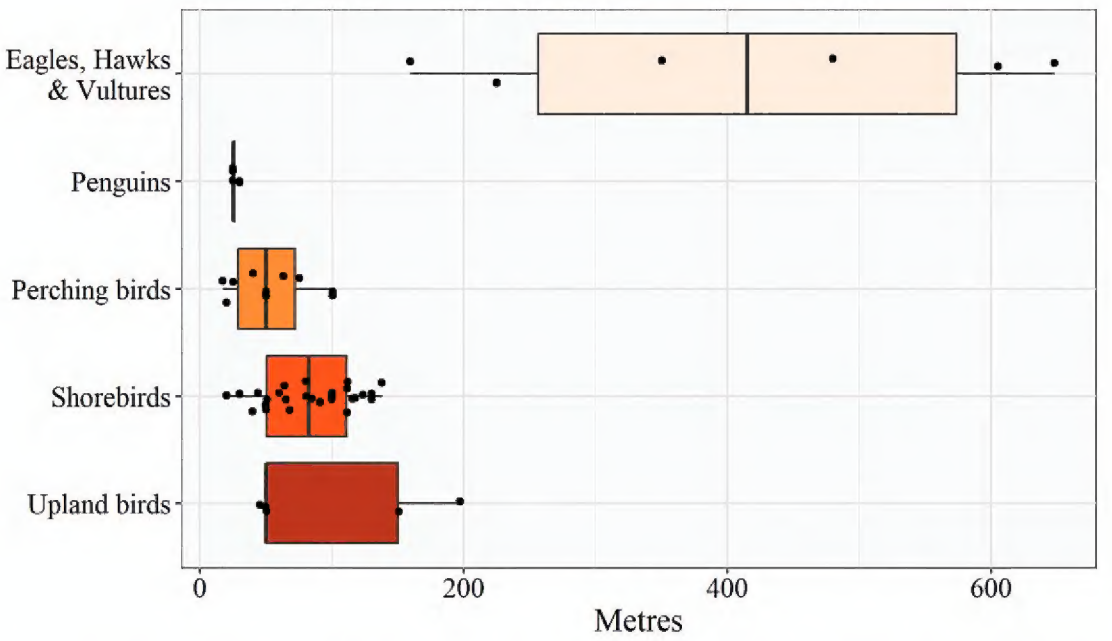


**Figure 4.** Distance of effect thresholds across bird orders. Threshold distances of birds by taxonomic group. Black dots indicate individual data points. The only owl threshold distance ($x$ = 55 m) is not presented in this figure. Boxplots indicate median and 25$^{th}$ and 75$^{th}$ percentiles. Whiskers extend to data 1.5 times the interquartile range.

2001; Jorgensen et al. 2016). Ungulate species were the best represented mammalian group and had a broad distribution of effect distance thresholds from 40 to 1000 m (Borkowski et al. 2006; Preisler et al. 2006).

Research that identified effect thresholds were heavily skewed towards studies that measured the distance from which there was a behavioural response from wildlife. Few studies in recreation ecology identified a physiological or reproductive response threshold or showed a threshold of visitation numbers or density of human infrastructure. Previous work has shown that even low human presence can impact wildlife habitat use (Cornelius et al. 2001; Spaul and Heath 2016; Patten and Burger 2018); however, isolating and interpreting the impacts of visitor numbers or infrastructure density is arguably more difficult than the physical distance to humans or trails, which could explain the sparse examples of density impacts in our findings. Further, short-term behavioural responses to human disturbance can be difficult to link directly to population consequences (Gill et al. 2001). With the increasing visitation pressure on the world's protected areas (Schulze et al. 2018), there is a great opportunity and need to focus on identifying physiological or reproductive effect thresholds of recreation and to measure when visitor numbers begin to deleteriously impact wildlife.

We found that the median threshold distance for birds and mammals across different recreation activities ranged from 40 to 111.5 m, but that the values were not significantly different amongst groups of recreation activities (Fig. 5). Though not statistically significant, the hiking-only recreation group for both mammals and birds had median threshold distance approximately half the magnitude of the non-motorised multiple-use or motorised recreation. This points to the magnitude of influence that even non-motorised recreation can have on the disturbance of wildlife (Stalmaster and Kaiser 1998; Reimers et al. 2006). Large buffer zones around human activities should

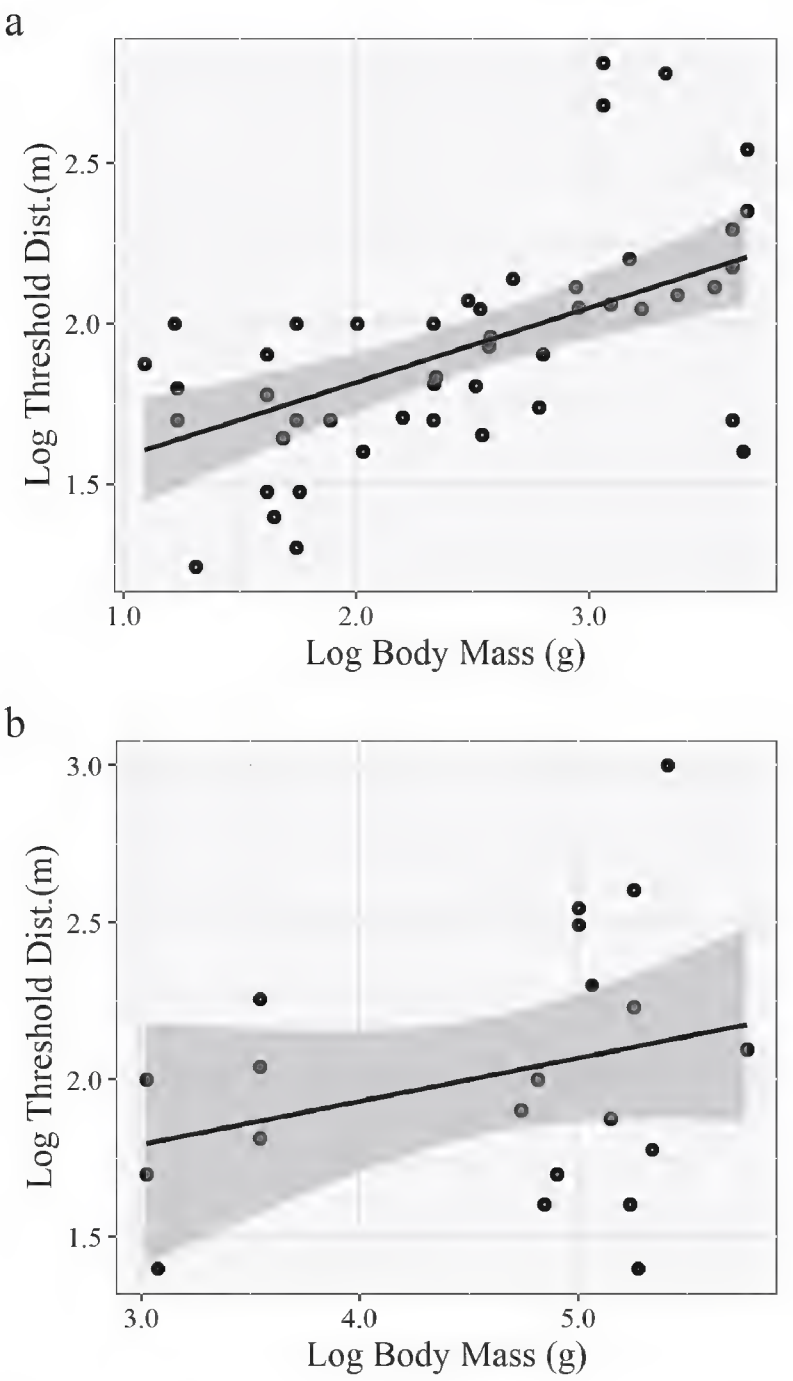


**Figure 5.** Wildlife body mass as a predictor of effect threshold distance. Regression analysis of body mass as a predictor for a taxon's effect distance threshold for (**a**) birds and (**b**) mammals. Black dots indicate individual observations and the shaded area represents the 95% confidence interval.

always be considered during the planning and maintenance of parks and protected areas (Miller et al. 1998; Keeley and Bechard 2011). Based upon on our findings, efficient trail systems with significant gaps of at minimum 250 m between any two trails provide some undisturbed areas for most wildlife species. The suppression and restoration of social trails (i.e. non-designated informal trails) maintain these buffer zones between trails, one of several conservation benefits of reducing these unplanned features. However, even intact buffers between trails do not ensure all species will have areas free of human disturbance.

We found a positive correlation between flighted bird body mass and effect distance threshold, but no relationship between mammal body mass and effect distance threshold. Flight initiation distance, the predominant response measure in our review (Table 1), is shown to be significantly correlated with bird body mass (Piratelli et al. 2015). Similarly,

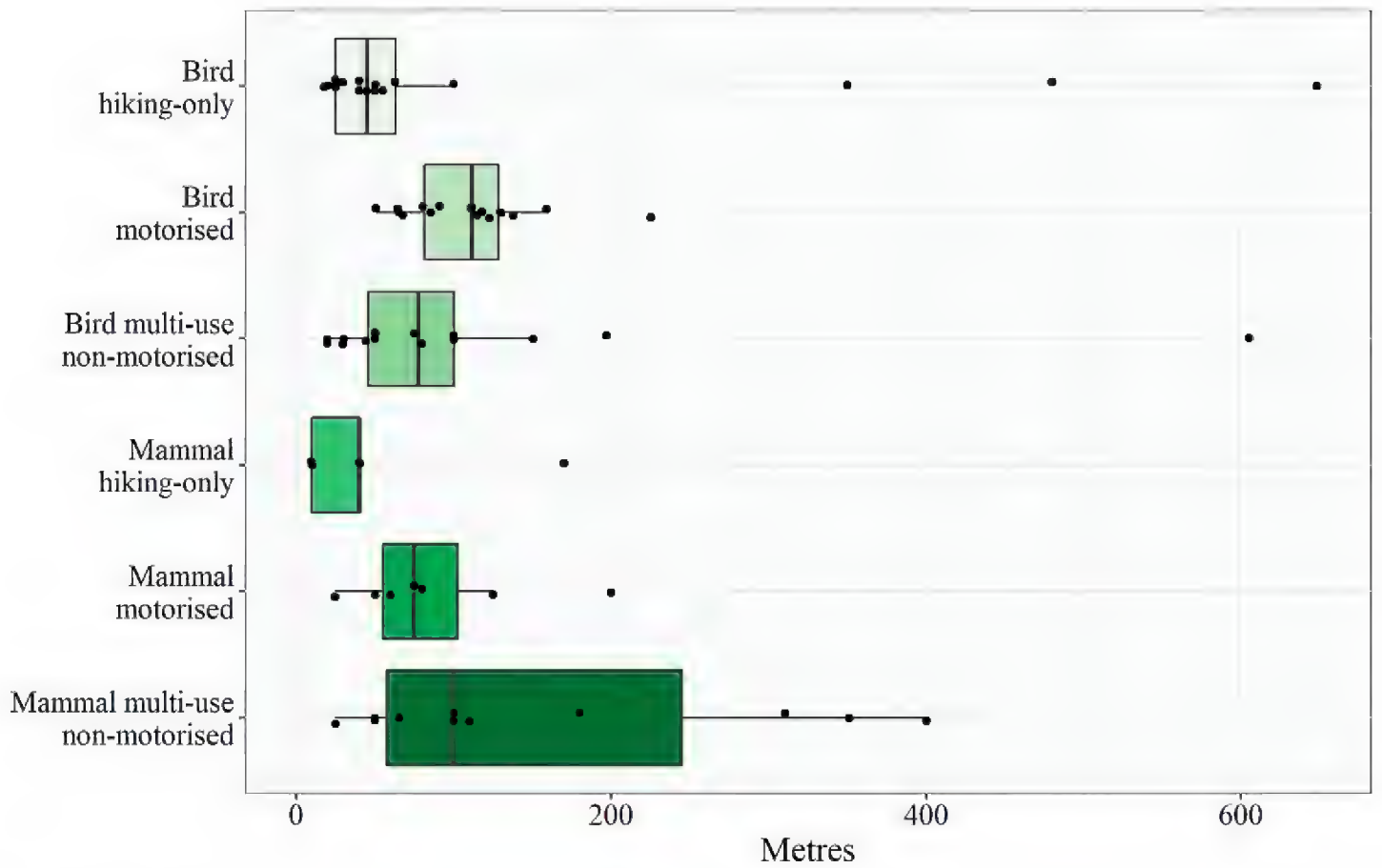


**Figure 6.** Effect thresholds across groups of recreation activities and taxa. Black dots indicate individual data points. Boxplots indicate median and 25$^{th}$ and 75$^{th}$ percentiles. One outlier of 1000 m is not shown for mammal motorised. Whiskers extend to data 1.5 times the interquartile range.

Blumstein et al. (2005) found a significant relationship between body mass and alert distance from a sample of 150 species, suggesting that bird body mass could be a good predictor for conservation decision-making. However, this suggestion could be tempered by Larson et al. (2019) who found that high recreation levels had greater negative effects on small bird abundance than on large bird abundance. This indicates the importance of taking multiple response measures into account and understanding their link to individual fitness or population growth when making conservation policies and guidelines.

The relationship between mammal body mass and human disturbance distance appears less clear than for birds. While there is evidence that smaller-sized mammals are more tolerant of human disturbance and the proximity to human settlements (Battisti et al. 2019; Lhoest et al. 2020), these studies incorporate human disturbances beyond non-consumptive recreation. Larson et al. (2019) did find a similar lack of relationship between mammal body size and recreation effects on abundance, rather than effect distance. In addition, what influence human habituation may play in altering this relationship could not be quantified, though some studies in our analysis did state the likelihood of wildlife individuals habituated to human presence (Lott and McCoy 1995; Klailova et al. 2010). Ultimately, threshold data was much sparser for mammals than birds, thus making it difficult to draw any strong inferences from these results.

There were few examples of recreation infrastructure thresholds, beyond those describing distance to trail. Despite the small sample size, the findings were consistent: infrastructure, even at low densities, can be a contributing factor to altering the habitat

use of birds and mammals (Braunisch et al. 2011; Harris et al. 2014; Richard and Côté 2016). At a regional scale, recreation infrastructure can also further exacerbate underlying human-wildlife conflicts (Ménard et al. 2014) and fragment habitats (Whittington et al. 2005). Better understanding of how the density and effect distance of buildings and trails influences the behaviour and survival of wildlife species is paramount for the creation of informed regulatory guidelines.

The detection of threshold effects, if present, can be constrained by the spatiotemporal extent and overall design of a study. In addition, the effect threshold of human presence or infrastructure may be outside the boundaries of the study area or may be difficult to disentangle from correlated effects of other variables. Future researchers should consider how their experimental design could isolate recreation activities and species to support the detection of specific quantitative thresholds. Rodríguez-Prieto and Fernández-Juricic (2005) provide a valuable example demonstrating the quantitative threshold of the effect of recreation activity on the Iberian frog (*Rana iberica* Boulenger, 1879). Their study design incorporated systematic exposure of the species of interest to human disturbance, which provided direct and measurable flight initiation distances of individual animals from humans. Although this study system is likely easier to control and observe than studies of larger bodied species, it is an important example of implementing a study design to quantify a threshold effect of recreation disturbance and how to effectively represent these results.

There remains a need to understand when and where recreation activities are affecting species negatively or positively (Larson et al. 2016). However, to provide information for future designation and management of recreation use, researchers must go beyond simple hypothesis testing. Studies that focused on categorical variables (e.g. low versus high visitation rates, hikers versus mountain bikers) to examine the potential effects of a recreation treatment, rarely identified the threshold at which the recreation activity may begin or cease to affect an animal species. Asking when and to what extent a species is being disturbed and measuring beyond the spatial or temporal magnitude where the disturbance is expected to begin or end allows researchers to identify important thresholds of recreation disturbance. Researchers should not provide a quantitative recommendation that is not justified by their results, but, where possible, researchers should provide resource managers with clear guidance and conservative estimates to support science-based management decisions. Ultimately, these thresholds allow for more informed and effective management decisions and a higher probability of successful conservation of species.

## Acknowledgements

We would like to thank Tony Nelson, the Sonoma Land Trust and the Gordon and Betty Moore Foundation for their support of this project. We would also like to thank Jessica Sushinsky, Stacey Lischka, Sasha Keyel and Miguel Jimenez for discussion and support. Two anonymous reviewers provided very useful feedback and greatly improved the article.

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## Supplementary material 1

**Table S1. Articles of recreation effect thresholds results and metadata**

Authors: Jeremy S. Dertien, Courtney L. Larson, Sarah E. Reed

Data type: articles metadata

Explanation note: All articles within our database that identified a quantitative threshold of where human disturbance on wildlife via non-consumptive recreation began or ended. Articles are listed species specifically or by the lowest taxonomic group where the threshold was identified..

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Link: https://doi.org/10.3897/natureconservation.44.63270.suppl1